Measures Towards Nearly Zero Energy Houses in Cyprus

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Abstract

According to the recast of the Energy Performance of Buildings Directive (EPBD), after 2020 all new buildings should have nearly zero energy consumption. For the public sector this Directive will be applied two years in advance. Although the term "nearly zero" is not quantified in the Directive, here it means a total primary annual energy consumption of less than 15 kWh/m^2. There is thus a need to investigate ways to achieve this nearly zero energy consumption first by applying various thermal load reduction measures and then renewable energy systems. Therefore, in this paper, various measures are investigated as applied to a hypothetical typical house, 196 m^2 in area located in Nicosia, Cyprus, to achieve this low energy consumption. These measures concern the use of insulation, type of glazing, natural ventilation, shape of the building and use of overhangs. The building is modeled with TRNSYS using the detailed Transfer Function Method (TFM). The baseline scenario, which involves a building with non-insulated walls and roof and single-glazed windows, shows a consumption of 297.7 kWh/m^2 per year. From the measures investigated the most effective are the insulation and the use of advanced glazing systems, which reduce drastically the cooling load requirement but increase the heating load, although the total annual effect is the reduction of the total consumption. Natural ventilation has a smaller but significant effect. A solar water heater is also installed on the house to provide the hot water requirements of the occupants. The total contribution of this system is 6480 MJ or 9.2 kWh/m^2 per year. The results show that a considerable reduction can be obtained from the above measures, which could lower the consumption to 88.27 kWh/m^2 per year, but they are not enough to reach the target required unless an additional renewable energy system is installed to produce some of the energy consumed. Therefore, for the best case of measures examined, a 3.3 kWp polycrystalline PV system is required to be installed so as the building could achieve the required consumption of 15 kWh/m^2.

Keywords

Energy Performance of Buildings Directive; Nearly Zero Energy Consumption; TRNSYS; Renewable Energy

Introduction

The significance of energy consumption in residential building sector is well known. Several studies published recently, have shown that in this sector there is a significant potential of energy savings.

Buildings consume about 40% of the final energy in European Union (EU) countries and this consumption creates about 30% of their carbon dioxide emissions [1]. A number of studies show that there is a large potential for the saving of energy in this sector [2]. For the case of Cyprus, the fact that until recently there was no legislation concerning the insulation of buildings, the possible energy savings are even larger [3]. Based on the target set by EU for increasing the safety of energy supply [4], the reduction of greenhouse gas emissions based on Kyoto Protocol [5] and the general policy for improving the energy performance, the European Commission issued the directive 2002/91/EC - energy performance of buildings in 2002 [6]. This Directive implies that members need to specify their national methodology for the estimation of the energy performance of their buildings and to establish a system of energy certification. Such actions however need to be done after the buildings are classified into categories and the specification of the highest limits of energy consumption per category [7]. In Cyprus, the Directive is harmonized into the National system with the Law N.142 (I)/2006. Additionally, Cyprus adopted also Directive 2006/32/EC on energy end-use efficiency and energy services [8], which among others requires Member States to establish and achieve a national indicative target in energy savings.

A number of studies were presented recently in the area of achieving either zero or nearly zero energy consumption in buildings. The term "zero energy house" indicates a balance between energy production and consumption or in simple terms indicates a house that

produces the energy it spends. Ferrante and Cascella [9] presented the zero energy balance and zero on-site CO_2 emission housing development in the Mediterranean climate, whereas Lund et al. [10] presented zero energy buildings and mismatch compensation factors, i.e., the mismatch problem of zero energy and zero emission buildings (ZEBs). Sadineni et al. [11] presented the economic feasibility of energy efficiency measures in residential buildings in the Desert Southwest region of the USA (Las Vegas). It is found that a typical house, with the cost-effective upgrades installed, consumed 42.5% less annual energy compared to a home built to code. A 3.19 kWp PV system installed on the south-facing roof of the home can generate 5982 kWh annually, making it a net-zero (electrical) energy home. They concluded that PV systems in Las Vegas have encouraging benefit cost ratios when federal and state rebates are considered.

Many authors focus their analysis on zero carbon emissions, like the study of Xing et al. [12] on zero carbon buildings refurbishment. Germany's path towards nearly zero-energy buildings which enable the greenhouse gas mitigation potential in the building stock is presented by Schimschar et al. [13]. Finally, Bojic et al. [14] examined a positive-net-energy residential building in Serbian conditions using mainly PVs.

In view of the recast of the Energy Performance of Buildings Directive (EPBD), after 2020 all new buildings should have nearly zero energy consumption. For the public sector this Directive will be applied two years in advance. The term "nearly zero" can have many definitions, in this work however the German Passive House (Passivhaus in German) standard is adopted which specifies a total primary annual energy consumption of up to 15 kWh/m^2. There is thus a need to investigate ways to achieve this zero or nearly zero energy consumption. In this paper, various measures are investigated as applied to a hypothetical typical house, 196 m^2 in area located in Nicosia, Cyprus, to achieve this energy consumption. These measures concern the use of insulation, type of glazing, natural ventilation, shape of the building and use of overhangs.

TRNSYS Program Overview

The building considered in this study is modeled with the transient systems simulation TRNSYS program, using the detailed Transfer Function Method (TFM). The program has a modular structure, i.e., it has many readymade components and each module contains a mathematical model for each system component. The building model in TRNSYS is created in simulation studio, where the various modules which are required are dragged and dropped, and connected together. Additionally, the user has to specify for each connection which outputs from one module is input to the other/s.

For the present study the main component used is TRNSYS Type 19 model. This is used to estimate the heating and cooling loads for a typical hypothetical house by estimating on an hourly basis, for all hours of the year, the heating and cooling loads induced from walls, windows, roof and floor.

Type 19 module has two basic modes of operation; the energy rate and the temperature level control. In the present study the temperature level control mode is used, because with this mode the temperature of the building/zone is maintained between specified upper and lower limits and the energy required to maintain the zone in the range of the specified temperature is the output of the module. Additionally, the zone humidity ratio is allowed to float between a maximum and a minimum limit specified by the user and thus the humidification or dehumidification energy is estimated. Moreover, heat may be added or removed either by the ventilation flow stream or by an instantaneous heat gain input. Finally, a controller is used in conjunction with this mode to control the heating or cooling equipment.

TRNSYS Type 19 module uses the transfer function coefficients for the estimation of heating and cooling loads [15]. According to the program manual, these coefficients should not include the radiative resistance at the inside surface, therefore the standard ASHRAE inside surface resistance (E0), which includes both the convective and radiative resistances, is not used.

Additionally, because radiation is handled separately by TRNSYS Type 19, only an inside convective resistance of 0.1044 m^2-K-hr/kJ is included when deriving the transfer function coefficients. This value is specified in the parameter list of Type 19 for calculating the sol-air temperatures. The standard ASHRAE external surface resistance (A0) is used as it is, as only the wind speed is used to calculate the sol-air temperature in the module. It should be noted that the required coefficients are estimated for each construction considered using a different program called PREP, which is provided with the TRNSYS program [15]. Tables 1, 2 and 3 indicate the most important parameters used in the calculations with TRNSYS Type 19 module. In these Tables the parameter numbers shown refer to the TRNSYS numbering system.

TABLE I IMPORTANT ZONE PARAMETERS USED IN THE CALCULATIONS WITH TRNSYS TYPE 19

Parameter	Description	Set value
1-Mode	1-energy rate control, 2-temperature level control	2
2-V_a	Zone volume of air [m^3]	147
3-K1	Constant air change per hour	1
4-K2	Proportionality constant for air change due to indoor-outdoor temperature difference [$(°C)^{-1}$]	0.017
5-K3	Proportionality constant for air change due to wind effects [$(m/s)^{-1}$]	0.049
6-Cap	Capacitance of room air and furnishings [kJ/°C]	500
7-N	Number of total surfaces comprising room description	7
8-T_o	Initial room temperature; also used for calculation of Inside radiation coefficients [°C]	15
9-w_o	Initial room humidity ratio [kg water/kg dry air]	0.0075
10-T_{min}	Set point temperature for heating [°C]	21
11-T_{max}	Set point temperature for cooling [°C]	25
12-w_{min}	Set point humidity ratio for humidification [kg water/kg dry air]	0.005
13-w_{max}	Set point humidity ratio for dehumidification [kg water/kg dry air]	0.008
INPUT NUMBER		
1-T_a	Ambient temperature [°C]	from TMY file
2-w_a	Ambient humidity ratio [kg water/kg dry air]	from TMY file
3-T_v	Temperature of ventilation flow stream [°C]	from TMY file
4-v	Mass flow rate of ventilation flow stream [kg/hr]	0
5-w_v	Humidity ratio of ventilation flow stream [kg water/kg dry air]	from TMY file
6-I	Rate of moisture gain (other than people) [kg/hr]	0
7-N_{people}	Number of people in every zone	1
8-I_{act}	Activity level of people	2
9-Q_{IR}	Radiative energy input due to lights, equipment, etc. [kJ/hr]	750
10-Q_{int}	Sum of all other instantaneous heat gain to space [kJ/hr]	0
11-W	Wind-speed [m/s]	from TMY file

TABLE II IMPORTANT WALL PARAMETERS USED IN THE CALCULATIONS WITH TRNSYS TYPE 19

Parameter	Description	Set value
4-r	Reflectance of inner surface to solar radiation	0.7
5-α	Absorptance of exterior surface to solar radiation	0.65
7-h_c	Inside convection coefficient [kJ/hr-m^2-C]	9.58

TABLE III IMPORTANT WINDOW PARAMETERS USED IN THE CALCULATIONS WITH TRNSYS TYPE 19

Parameter	Description	Set value
5-t_d	Transmittance for diffuse solar radiation	0.833
6-$h_{c,i}$	Inside convection coefficient [kJ/hr-m^2-°C]	31.5
7-N_I	Number of surfaces on which transmitted beam radiation strikes	1
8-k	First surface number of which beam of radiation strikes	5 (floor)
INPUT NUMBER - Window Mode 1		
1-I_T	Total incident radiation [kJ/m^2-hr]	calculated by TRNSYS
2-I_{bT}	Incident beam radiation [kJ/m^2-hr]	calculated by TRNSYS
3-t	Overall transmittance for solar radiation	0.833
4-U_g	Loss coefficient of window (+ night insulation) not including convection at the inside or outside surface [kJ/hr-m^2-°C]	12.3
5-f_k	Fraction of incoming beam radiation that strikes surface k	1

For calculating the losses from the floor area the following equation is used [16]:

$$Q= F_2 P (T_i-T_o) \quad (1)$$

where:

Q= heat loss through perimeter [W]

F_2= heat loss coefficient per meter of perimeter [=0.97 W/m-K]

P= perimeter of exposed edge of floor [m]

T_i = indoor temperature [°C]

T_o= outdoor temperature [°C]

To run a simulation for a system affected by the ambient conditions, appropriate weather data are needed. Particularly, to perform detailed building simulations with TRNSYS, hourly weather data are required mainly provided in the form of a typical meteorological year (TMY) file. Therefore, to obtain the building load, TRNSYS runs through the hourly values of various weather parameters (mainly, global and beam radiation, ambient air temperature, humidity ratio, and wind speed and direction) included in a TMY file. For this purpose the TMY for Nicosia-Cyprus, developed by the author [17], is employed. This has been generated from hourly measurements, of the above weather parameters, for a seven-year period, from 1986 to 1992.

The general climatic conditions of Cyprus are mostly very sunny with an average solar radiation of 5.4 kWh/m^2 per day on a horizontal surface. This solar energy input is particularly high during the dry summer period that lasts from April to October. During the rest of the year sunshine duration remains considerable even in the coldest winter months.

Typical House

As was seen above, the program TRNSYS is used to simulate the temperature variation and the thermal loads of a hypothetical typical house in Nicosia-Cyprus. The hypothetical model house, illustrated in Fig. 1, has a floor area of 196 m^2 and consists of four identical external walls, with a length of 14m and a height of 3m, with a window opening of 5.2m^2 on each wall.

The floor area of the hypothetical model house is approximately equal to the floor area that modern houses in Cyprus have. Moreover, the window opening area is also approximately equal to the area that a typical house would have, but as a simplification, instead of considering a number of windows on each wall, only one window is considered. Since the same model is used to evaluate and compare the load for various constructions this simplification is not important but will assist in drawing conclusions since similar constructions are present on every wall. As shown in Fig. 1, the model house is further divided into four identical zones and the walls separating the four zones are considered as partition walls. In this way the model house has in each coordinal direction a wall without window and a wall with window so as to investigate the effect of both cases. It should be noted that for every zone a separate TRNSYS Type 19 unit is necessary. The results presented in the following sections are for the thermal load of the whole house and are obtained by summing up the loads from all four zones of the model house.

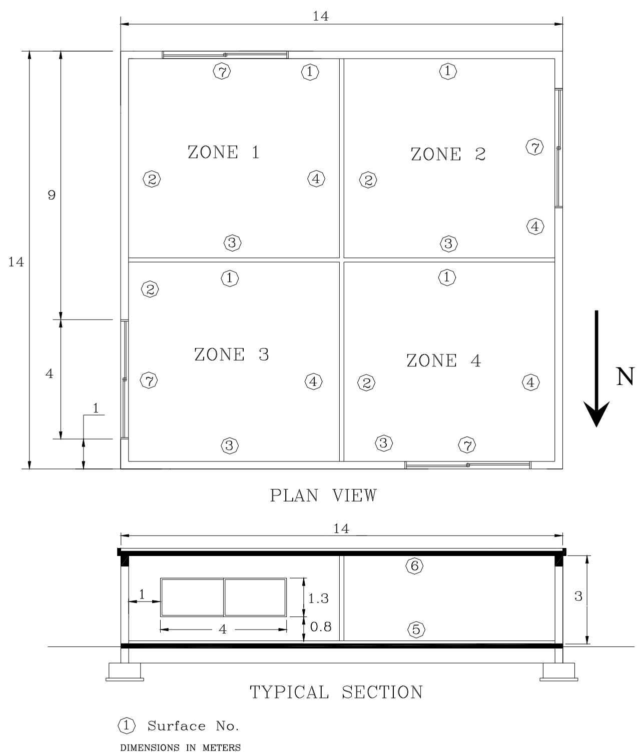

FIG. 1 MODEL HOUSE

Houses in Cyprus are usually built with hollow bricks made of fired clay. The density of these bricks is 940 kg/m^3 and their thermal conductivity is 0.310 W/m-K, for a temperature difference of 15°C (20-35°C). So all wall constructions considered include this type of brick.

Simulation Results

All the results presented in this section are taken from references [3] and [18] and adapted for the purpose of the present work. These include the effect of various measures used to reduce the energy consumption of the hypothetical model house like insulation, glazing and internal shading, ventilation, shape of the building, and the effect of overhangs.

Effect of Insulation

The first measure investigated is the effect of wall and roof insulation on the heating and cooling loads of the model house. Particularly, the energy demand of a single wall, a double wall with 25 mm insulation and a double wall with 50 mm insulation, as well as a single wall with no-roof insulation, a single wall with 25 mm roof insulation and a single wall with 50 mm roof insulation for the hypothetical typical house in Nicosia are estimated. The annual heating and cooling loads to keep the house at the target temperatures of 21°C during winter and 25°C during summer are shown in Table 4. The results show the importance of primarily the roof insulation and also the wall insulation. The insulation considered in all cases is polystyrene with thermal conductivity k=0.0344 W/m-K.

As it can be seen, the total demand for a non insulated hypothetical typical house is 297.51 kWh/m^2 and the cooling load is the dominant figure. This is considered as the baseline scenario in which no measure and no insulation is used. This was the typical way of construction until some years ago. The total energy demand for a dwelling with 50 mm wall insulation is reduced to 283.73 kWh/m^2 and for a dwelling with 50 mm roof insulation to 144.89 kWh/m^2 respectively. The respective value when both walls an roof are insulated with 50 mm insulation is 124.91 kWh/m^2.

Effect of Type of Glazing and Internal Shading

In this section an analysis of the impact of window glazing on the cooling load is presented. A number of cases are investigated which can partly obstruct solar radiation and offer a wide range of conductance. The cases considered are presented in Table 5.

The results of the simulations are summarized in Table 6. As it is observed, when compared to the corresponding construction with clear double glazing windows (case W1), a saving in the cooling load between 15.56 kWh/m^2 and 37.32 kWh/m^2 per year can result. The saving in cooling load for the house with 50 mm roof and wall insulation can be as much as 35.3% in the case that no extra lighting is used for window type W3. However as in the case of window type W3 the transmittance for visible radiation is only 0.41 extra lighting would be needed, depending on the occupant needs and minimum luminance value allowed. Assuming an extra 150 W lighting consumption, the savings reduce to 24%. On the contrary, window glazing will also reduce solar radiation transmission into the house, which would have been beneficial in the cold winter days. This effect will result in an annual increase of the heating load, which in the latter case would be 4.47 kWh/m^2 or 23.5%.

The analysis of the impact of internal shading on the cooling load is also examined. For the results, presented in Table 7, approximately half the transmittance (0.4 instead of 0.833) for solar radiation was used in the calculations, corresponding to a Venetian blinds shading device. As it is observed, a saving in the cooling load of 17.28-23.40 kWh/m^2 per year results, depending on the construction type considered. The saving increases with the amount of insulation of the construction resulting in savings of 8-20% of the cooling loads.

TABLE IV ANNUAL ZONE COOLING AND HEATING LOAD PER UNIT FLOOR AREA

Load	*Single wall no roof insulation (kWh/m^2)*	*No-roof insulation*		*Single not insulated wall*		*Both wall and roof insulation*
		Double wall with 25 mm insulation (kWh/m^2)	*Double wall with 50 mm insulation (kWh/m^2)*	*25mm roof insulation (kWh/m^2)*	*50 mm roof insulation (kWh/m^2)*	*50 mm wall and 50 mm roof insulation (kWh/m^2)*
Cooling at 25°C	215.82	211.99	210.71	125.82	117.60	105.83
Heating at 21°C	81.69	75.23	73.02	33.19	27.29	19.08
Total	297.51	287.22	283.73	159.01	144.89	124.91

TABLE V PROPERTIES OF WINDOW GLAZING

Case	**Window type**	**Unit conductance (U, W/m^2-K)**	**Unit conductance (U, kJ/hr-m^2-K)**	**Transmittance for visible radiation (τ_v)**
W1	Clear double glazing	3.42	12.3	0.80
W2	Reflective double glazing, bronze	2.27	8.2	0.10
W3	Low-emissivity double glazing, bronze	1.89	6.8	0.41

TABLE VI EFFECT OF WINDOW SHADING ON ANNUAL COOLING LOADS

Wall and roof construction	Window Type (Table 5)	Cooling load (kWh/m^2)	Cooling load decrease, compared to case W1 (kWh/m^2)	Cooling load decrease, compared to case W1 %	Heating load (kWh/m^2)	Heating load increase, compared to case W1 (kWh/m^2)	Heating load increase, compared to case W1 %
Single wall, no roof insulation	W1	215.82	-	-	81.69	-	-
	W2	199.84	15.97	7.4	85.39	3.70	4.5
	W3	187.37	28.44	13.2	91.50	9.81	12
50 mm roof and wall insulation	W1	105.83	-	-	19.08	-	-
	W2	84.29	21.55	20.4	23.75	4.67	24.5
	W3	68.52	37.32	35.3	31.57	12.48	65.4
50 mm roof and wall insulation plus extra lighting	W1	105.73	-	-	19.08	-	-
	W2+ 100W	90.27	15.56	14.7	20.18	1.10	5.8
	W3+ 150 W	80.47	25.36	24.0	23.56	4.47	23.5

TABLEVII EFFECT OF WINDOW INTERNAL SHADING ON ANNUAL COOLING LOADS

Wall and roof construction	Cooling load (kWh/m^2)	Cooling load with window shading (kWh/m^2)	Cooling load difference (kWh/m^2)	Cooling load difference %
Single wall, no roof insulation	216.32	199.04	17.28	8.0
Double wall with 50 mm insulation, no roof insulation	210.71	193.17	18.05	8.6
Single wall, 50 mm roof insulation	117.60	94.20	23.40	19.9

Effect of Ventilation

ASHRAE Standard 62 on the ventilation and acceptable indoor air quality in low-rise residential buildings, specifies the minimum requirements for mechanical and natural ventilation in spaces intended for human occupancy within single-family houses and low-rise multifamily structures. For the hypothetical model house of 196 m^2, assuming three bedrooms as in typical Cypriot houses, the required mechanical or natural ventilation is about 0.31 air changes per hour (ACH). This requirement, according to a study in the stock of buildings in the USA, can be met through infiltration alone, since the buildings are quite leaky [19]. Also, according to Balaras [20], new buildings induce 0.2-0.5 air changes per hour by infiltration, while with the windows wide open during summer it is possible to achieve 15-20 ACH. The equation used in the calculations for TRNSYS Type 19 exceeds the requirements for the majority of the hours of the day, with the rest of the cases being near the required ACH. For this reason no extra rate of ventilation flow stream (parameter v, in Table 1) was introduced in the simulations.

In this section the effect of introducing naturally or mechanically ambient air into the space when the outdoor air is of a lower temperature than the indoor air during summer and of a higher temperature than the indoor air during winter is investigated.

Table 8 presents the annual cooling and heating loads for various roof constructions. As can be seen, in winter the load reduction arising from ventilation is minimal. In summer, ventilation leads to a reduction of about 1.6% to 6.3%, provided that the control unit will shut off ventilation when the sensible cooling effect produced is smaller than the latent load introduced.

Effect of House Shape

Generally, the exposed surface area of a building is related to the rate at which the building gains or loses heat while the volume is related to the ability of the building to store heat. Therefore, the ratio of volume to exposed surface area is widely used as an indication of the rate at which the building will heat up during the day and cool down during the night. A high volume to surface ratio is preferable for buildings that are desired to heat up slowly, as it offers small exposed surface for the control of both heat losses and gains [21].

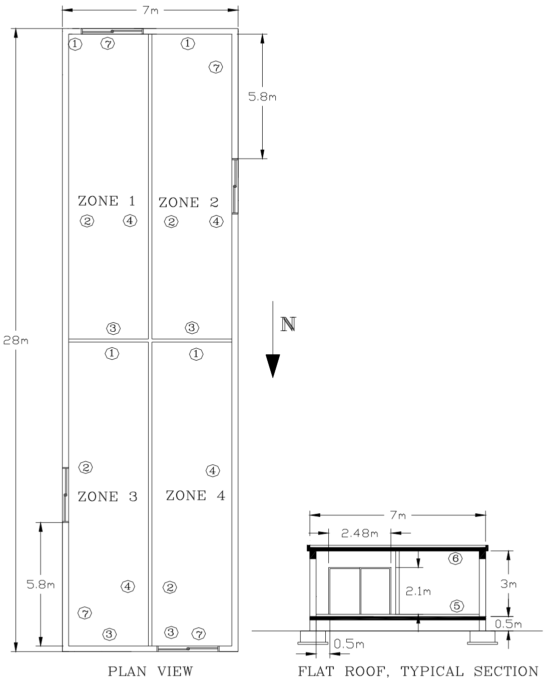

FIG. 2 MODEL HOUSE SHAPE 2.

In order to examine the effect of the shape of the building a new model house plan is necessary that will increase the wall area but will keep the same volume. This model, named Shape 2, is illustrated in Fig. 2. As can be seen, Shape 2 has half the width and double the length of the original model house (Shape 1) resulting in a wall perimeter of 70 m instead of 56 m of the original square model.

Table 9 presents the thermal load variation between the houses with different shapes. For this analysis two construction types were examined for every shape. These are the single wall model with no roof insulation and the 50 mm wall and roof insulation model. The results show that the elongated Shape 2 model has about the same cooling load but shows a significant increase in the heating load, between 8.2% and 26.7% with respect to the model house of Shape 1, depending on the construction type. Therefore, the results show that a smaller wall area to volume ratio is preferable for the Cypriot environment.

Effect of Overhangs

Overhangs are devices that obstruct direct solar radiation from entering a window during certain times of the day or year. This obstruction is desirable for reducing the cooling loads and avoids uncomfortable lighting in perimeter rooms due to excessive contrast. To investigate the effect of the overhang length a number of simulations were performed. For these simulations the overhang was assumed to be located 0.5 m above the window and extend 1 m on both sides of the window.

TABLE VIII ANNUAL COOLING AND HEATING LOADS FOR VARIOUS ROOF CONSTRUCTIONS INDICATING THE EFFECT OF VENTILATION

Air changes per hour	**Process**	**No-roof insulation**	**25 mm roof insulation**	**50 mm roof insulation**	**50 mm roof and wall insulation**
		Load (kWh/m²)	***Load (kWh/m²)***	***Load (kWh/m²)***	***Load (kWh/m²)***
0	Cooling	215.82	125.82	117.6	105.83
	Heating	81.69	33.19	27.29	19.08
	Total	297.51	159.01	144.89	124.91
1	Cooling	213.79	123.67	115.33	103.81
	Heating	81.69	33.18	27.28	19.08
	Total	295.48	156.85	142.61	122.89
3	Cooling	209.99	120.95	112.51	100.94
	Heating	81.63	33.16	27.27	19.07
	Total	291.62	154.11	139.78	120.01
5	Cooling	207.53	119.35	110.87	99.31
	Heating	81.53	33.14	27.22	19.04
	Total	289.06	152.49	138.09	118.35

TABLE IX ANNUAL THERMAL LOAD VARIATION BETWEEN HOUSES OF DIFFERENT SHAPES

Case	Model house type	Shape 1		Shape 2		Percentage difference in respect to Shape 1	
		Cooling load (kWh/m^2)	*Heating load (kWh/m^2)*	*Cooling load (kWh/m^2)*	*Heating load (kWh/m^2)*	*Cooling load*	*Heating load*
A	Single wall, no roof insulation	215.82	81.69	222.07	88.38	2.9%	8.2%
B	50 mm wall and roof insulation	110.77	17.78	110.54	22.54	-0.2%	26.7%

The total annual cooling and heating load difference for the model house constructed from walls and roof with 50 mm insulation, is presented in Fig. 3. As can be seen, the greater the overhang projection, the greater the cooling load decrease.

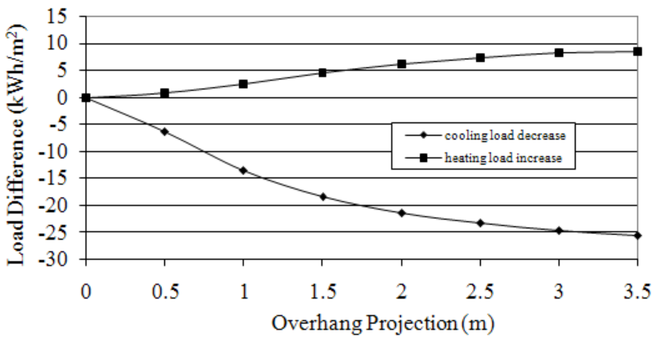

FIG. 3 ANNUAL LOAD DIFFERENCE PER YEAR AGAINST OVERHANG LENGTH FOR A MODEL HOUSE CONSTRUCTED FROM WALLS AND ROOF WITH 50 MM INSULATION

The heating load increases however, since some useful solar radiation is also obstructed during the cold winter days. The difference between the cooling and heating load increases with increasing overhang projection because greater amounts of direct and diffuse radiation will be obstructed both during summer and winter. Therefore, it would be advantageous to use long overhang projections in the summer that could be retracted in winter but in 'real' buildings the strategy will be based not only on economic but also on aesthetic reasons.

Combination of Measures

When the recast of the Directive will be put in effect no houses will be built without any insulation. Although the current insulation guide requires a minimum of 25mm of good insulation in order to reduce the loads further, a bigger thickness of insulation will have to be used. By considering a model house with the following combination of measures:

- 50mm insulated roof and walls,
- square shape,
- use of low emitting double glazing window with 150W extra lighting and
- 5 ACH ventilation

will result in an annual cooling load of 73.95 kWh/m^2 and an annual heating load of 23.52 kWh/m^2. Therefore, the annual total load will be 97.47 kWh/m^2, which is the minimum it can get according to the prevailing weather conditions of Nicosia, Cyprus and the application of the above measures. To convert these loads into primary energy the cooling load need to be divided by SEER (Seasonal Energy Efficiency Ratio), where a value of 3.2 is considered in this work and multiplied by 2.7 the factor to convert the electrical kWh into primary energy kWh. Similarly the heating load needs to be divided by the SCoP (Seasonal Coefficient of Performance), where a value of 0.9 is considered in this work and multiplied by 1.1 the factor to convert the thermal kWh into primary energy kWh. By performing these calculations the primary cooling load is 62.4 kWh/m^2 and the primary heating load is 31.2 kWh/m^2, which give a total of 93.6 kWh/m^2. Both seasonal coefficients take into account the efficiency of the main equipment (boiler or chiller) the heat loss in pipes and the energy required by pumps and fans.

It should be noted that in this optimal case the measures that proved to be the most efficient in thermal load reduction (heating and cooling) were considered. Additionally, no overhangs and no internal shading were considered, the former because is the usual case for Cyprus and the latter because its function is user dependent.

Use of Renewable Energy Sources and Conclusions

It is a habit in Cyprus to install in all houses a solar water heater. Details and performance analysis of such a typical system operating in Nicosia, Cyprus can be seen in [22].

Therefore, a solar water heater is considered to be installed on the hypothetical typical house. Such a system provides annually 80% the hot water needs of the occupants and the total contribution of such a system is 6480 MJ (1800 kWh) or 9.2 kWh/m^2 per year [22]. As was seen above the coefficient to convert this energy into primary energy is 1.1, so the primary energy supplied by the solar water heating system is 10.1 kWh/m^2.

By subtracting the energy supplied by the solar water heater, the net annual load is reduced to 83.5 kWh/m^2 per year (total 16,366 kWh per year).

Therefore, the measures considered and the use of a solar water heater are not enough to reach the target of less than 15 kWh/m^2 required, unless an additional renewable energy system is installed to produce some of the energy consumed. The total production of such a system should be 13,422 kWh per year obtained by subtracting 15x196 = 2940 kWh from the total of 16,366 kWh.

In Cyprus the most promising renewable energy systems are the ones based on solar radiation as the wind potential of the island is very low and possible application of domestic size wind turbines will create aesthetic and noise problems. Two such systems could be considered a solar heating and cooling system and a photovoltaic system. As one solar thermal system is already employed in the model house, in this work a PV system is considered. In Cyprus three types of PV panels are applied; polycrystalline, monocrystalline and panels made from amorphous silicon. The most popular are the polycrystalline ones.

Therefore, for the best case of measures examined, and by considering the remaining load that is required to be covered, which can be converted into electrical energy by dividing by the factor 2.7 as explained above, is 4971.1 kWh. Therefore, a 3.3 kWp polycrystalline PV system is necessary to be installed so as the building could achieve the required consumption of 15 kWh/m^2 or 4.04 kWp to cover the remaining load completely. This is because in Cyprus 1500 kWh/year are produced for each kWp of a polycrystalline PV system [23]. Such a system, obtaining the nearly zero condition, will require 19 panels which have and area of 0.76x1.6 m^2 and produce 180 Wp each. These panels will require a total area of 23 m^2 installed in rows. For the case of zero energy condition 23 PV panels will be required with a total area of 28 m^2.

In order to estimate the distance between the rows the shadow effects for the site under investigation is required. This can be estimated by using the lowest noon altitude angle, α_n, which occurs at December 21. During this day the solar declination is equal to -23.5°. The noon altitude angle, α_n is given by [24]:

$$\alpha_n = 90° - L + \delta \qquad (2)$$

Where L is the latitude angle of the location under consideration (35°). Therefore:

$$\alpha_n = 90° - 35 - 23.5 = 31.5°$$

The PV panel height is equal to 1.6 m installed at 30° (optimum angle used in Cyprus for such systems). A diagram showing the arrangement of installing rows of PVs by avoiding the shadowing effect is shown in Fig. 4. As can be seen a minimum gap of 1.31 m is required between rows to avoid shading.

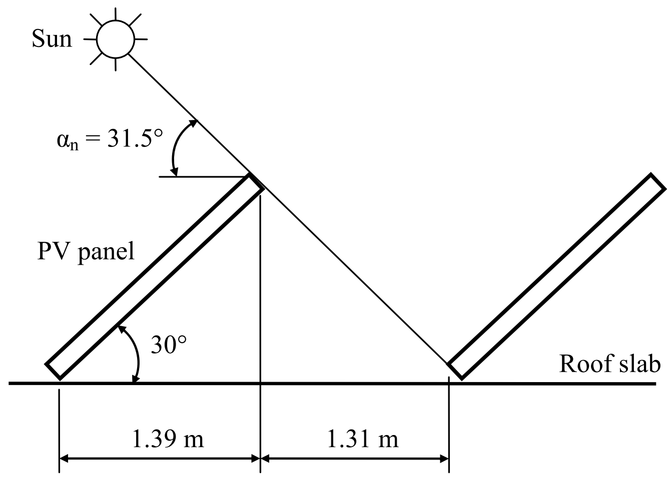

FIG. 4 ESTIMATION OF THE SHADOWING EFFECT

By leaving about 2 m on each side of the building, for aesthetic reasons (to avoid visibility problems), then a maximum of 14 panels will fit in each row. This means that a maximum of two rows will be required in either case and there is plenty of area on the roof to accommodate both the PV and the solar water heater.

Nomenclature

α_n: Noon altitude angle [degrees]

δ: Solar declination [degrees]

F_2: Heat loss coefficient per meter of perimeter [W/m-K]

L: Latitude angle [degrees]

P: Perimeter of exposed edge of floor [m]

Q: Heat loss through perimeter [W]

T_i: Indoor temperature [°C]

T_o: Outdoor temperature [°C]

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